University of Tabriz

Journal of Civil and Environmental Engineering
Volume 51 (2021), Issue 1 (Spring), 47-58

EXTENDED ABSTRACT

Numerical evolution of Reinforced Concrete Beam-Column Subassemblages under Progressive Collapse

Ali Hadidi *, Morteza Kamalvand

Faculty of Civil Engineering, University of Tabriz, Tabriz 5166616471, Iran

Received: 04 January 2018; **Accepted:** 23 June 2019

Keywords:
Nonlinear finite element analysis, Progressive collapse, Beam-Column subassemblage, Reinforced concrete frames.

1. Introduction

Progressive collapse of building structures typically occurs when an abnormal loading condition causes a sudden loss in the structural capacity of one or more critical members, which leads to a chain reaction of failure and ultimately catastrophic collapse (Tohihi et al, 2014). In this research, based on the alternative load path (ALP) approach, using the three-dimension (3D) finite element (FE) method, numerical studies were conducted for the investigation of progressive collapse resistance of beam-column joints in reinforced concrete (RC) frame under loss of exterior ground column. The paper presents a simple and reliable FE model that predicted the nonlinear load-deflection response of tested RC joints conducted by other researchers. Experimental models including two sets of interior and exterior subassemblages were analyzed under monotonic loading to simulate gravity load on the damaged frame after a blast. In the numerical simulations, the nonlinear behavior of materials was modeled by appropriate constitutive laws. The comparisons between numerical and experimental responses highlighted the reliability of the proposed FE model. In addition, a parametric study is conducted using the validated models to investigate the effect of slab on the behavior of the subassemblages and the transverse reinforcement ratio and slab effects on the performance of substructures that covering both the interior and exterior joints.

2. Methodology

The numerical analysis was carried out by using the FE software package ABAQUS Finite Element Code (2012). The geometry, properties of the constituent materials, semi-static loading, and boundary conditions in the developed FE models are exactly similar to the tested specimens. The concrete damaged plasticity model (CDP) was used for defining concrete behavior in the plastic range. This model is based on the Lubliner et al (1989) studies and modifications made by Lee and Fenves (1998). A non-associated flow rule is assumed in the CDP model. Tensile cracking and compressive crushing are two main mechanisms of the concrete failure in the CDP model. The concrete constitutive laws based on the equivalent uniaxial strain concept proposed to date use the uniaxial constitutive law proposed by Saenz (1964) to describe the response of concrete in compression. An appropriate tension stiffening model, proposed by Bischoff and Paixao (2004) was used to simulate the tension stiffening behavior of the concrete. The steel reinforcement was modeled as an elastoplastic material with strain hardening beyond its elastic phase. It was assigned a bilinear stress-strain relationship, with the tangent modulus in the strain-hardening regime taken to be 0.01 of the elastic modulus. In this study, concrete is modeled as a 3-D solid continuum element with eight nodes and three degrees of freedom at each node as translation in the nodal x, y and z directions, called C3D8R. A truss element called T3D2 was used to model steel reinforcement bars. This element has two nodes with three translation degrees of freedom at each node. The embedded element option was used for connecting reinforcement bars

* Corresponding Author
E-mail addresses: a_hadidi@tabrizu.ac.ir (Ali Hadidi), m.kamalvand91@ms.tabrizu.ac.ir (Morteza Kamalvand).

(embedded element) to the concrete (host element). The nonlinear analysis was carried out with the displacement control method. In interior FE models, the constant axial load on the top of the column was applied as distributed loading while the vertical load at the end of the left beam was applied through a displacement control mode. Also, in exterior FE models, gravity loading on the beam was applied through a displacement control mode as a point load.

3. Results and discussion

3.1. Model validations

The failure mode of the FE beam-column subassemblages agrees well with tests for both the interior and exterior specimens. The predicted load–deflection response and load-carrying capacity of the developed FE models were compared with the results obtained from the experimental tests. The FE models and experimental results for the yield strength, ultimate strength and displacement corresponding to the ultimate strength are given in Table 4 & 5. Comparisons of the numerical and experimental results of all specimens showed that the vertical load versus vertical displacement responses obtained from the FE analyses were similar to the experimental observations. From the aforementioned observations and predictions of the global behavior using the FE analysis, the use of FE modeling techniques can, therefore, be further extended to study the behavior of the subassemblages by varying different parameters.

Table 1. Experimental and FE results of interior beam-column subassemblages.

Test specimen	FE model	Yielding strength (kN)		Deference %	Ultimate strength (kN)		Deference %	Static ultimate displacement (mm)		Deference %
		$P_{y,Exp}$	$P_{y,FE}$		$P_{u,Exp}$	$P_{u,FE}$		$\delta_{u,Exp}$	$\delta_{u,FE}$	
I1	FE I1	142.0	162	14	195.5	200.5	2.5	236	223.7	-5.2
I2	FE I2	160.8	171.2	6.4	204.9	211.7	3.3	243	241.3	-1.0
I3	FE I3	160.0	170.5	6.5	206.5	209.2	1.4	262	256.6	2.1
I4	FE I4	161	171.1	6.2	228.9	224.0	-2.1	310	314.9	1.5

Table 2. Experimental and FE results of exterior beam-column subassemblages.

Test specimen	FE model	Joint cracking (kN)		Deference %	Ultimate strength (kN)		Deference %	Static ultimate displacement (mm)		Deference %
		$P_{y,Exp}$	$P_{y,FE}$		$P_{u,Exp}$	$P_{u,FE}$		$\delta_{u,Exp}$	$\delta_{u,FE}$	
LS01	FE LS01	149.0	153.2	2.3	276.3	282.2	2.1	89.5	86.8	-3.0
LS02	FE LS02	149.7	153.0	2.2	298.6	299.6	0.0	82.5	81.7	-1.0
LS03	FE LS03	149.0	155.4	4.3	371.7	330.1	-11.2	91.2	88.4	-3.1

3.2. Parametric study

To study the effect of T-shaped beam on the response of subassemblages, two series of FE models with an added RC slab flange for the interior (Specimens I3 and I4) and exterior (Specimens LS01 and LS02) beam-column subassemblages, were created. The FE model results of both of the interior and exterior specimens showed the slab worked as a beam flange and significantly increased the stiffness and strength of the beam-column subassemblages when subjected to loss of its exterior ground column.

The exterior beam-column element just above the removed column also provides resistance and has a distinct. This indicates that the exterior beam-column element can provide additional strength and stiffness to redistribute the loading, which is originally carried by the column that is removed. To study this effect, one subframe having the same detailing of the beam and column components as that both of the interior and exterior specimens were modeled through FE modeling.

To study the effect of the slab on the response of subassemblages, the FE model of the subframe including the T-shape beam was modeled. Furthermore, the effect of the percentage of transverse reinforcement in the plastic hinge zone of the interior joint was investigated.

4. Conclusions

Based on the alternative load path approach, using the three-dimension finite element method, numerical studies were conducted for the investigation of progressive collapse resistance of beam-column joints in reinforced concrete frame under loss of exterior ground column. The numerical results were compared with experimental data available in literatures highlighting the reliability of the FE model. In addition, a parametric study is conducted using the validated. The major conclusions derived from this study can be summarized as follows.

The developed FE models managed to accurately predict the cracking patterns and failure mechanism of the tested specimens including the interior and exterior subassemblages. There was a very good agreement between the load-defection diagrams of the FE model with experimental tests for both the exterior and interior subassemblages. The FE results indicated the floor slabs can have a significant contribution to the resistance of a structure during the progressive collapse, which should not be ignored in the design stage. The slab increases the yielding and ultimate strength of the RC frame. However, the slab membrane effect could not be investigated because of the limitations of the 2D frame models that were utilized. The transversal reinforcement in the beam and joints can significantly improve the global behavior of RC frames in resisting progressive collapse caused by the loss of an exterior column.

5. References

Tohihi M, Yang J, Baniotopouls C, “Numerical evaluations of codified design methods for progressive collapse resistance of precast concrete cross wall structures”, Journal of Engineering Structures, 2014, 76, 177-186.

Lubliner J, Oliver J, Onate EA, “Plastic-Damage Model for Concrete, International Journal of Solids and Structures”, International Journal of Solids and Structures, 1989, 25 (3), 299-329.

Lee J, Fenves GL, “Plastic-damage model for cyclic loading of concrete structures”, Journal of Engineering Mechanics (ASCE), 1998, 124 (8), 892-900.

Saenz LP, “Discussion of equation f or the stress-strain curve of concrete by Desai and Krishnan”, ACI Structural Journal, 1964, 61 (9), 1229-1235.

Bischoff PH, Paixao R, “Tension stiffening and cracking of concrete reinforced with glass fiber reinforced polymer (GFRP) bars”, Canadian Journal of Civil Engineering, 2004, 31 (4), 579-588.